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INTRODUCTION

One of the most important developments in coal measure stratigraphy in the last fifteen years has been the study of the microspore content of coal as applied to the correlation of seams and of stages in the coal measure series. In their practical application such methods of correlation have many advantages over methods based on lithology and on relative thicknesses of strata ; they are also preferable in some respects to other palaeontological methods such as those based on plants and fresh water molluscs, as the results lend themselves readily to quantitative treatment. An account of the principles involved may be read in Raistrick and Marshall (1939, pp. 127-133), who describe the work as involving " making use of the coal itself, rather than, and in addition to, the fossils contained in the adjacent strata." It is sufficient to state here that the microspores were widely distributed and freely mixed by wind action, so that localities on the same horizon have very similar microspore assemblages ; successive horizons, on the other hand, have distinctively different assemblages which are related to changes in the flora in the intervening time.

Steady progress is being made in the correlation of seams by microspore content in England and the United States. In Australia work has been initiated by Dulhunty (1946) by a description of the microspore types present in the Permian coals of New South Wales, which has been followed by a study of their stratigraphical distribution. The purpose of the work here recorded on the Queensland Permian types is to provide a basis for future work on correlation of seams within some of the coalfields, and also to attempt a correlation of the Queensland series with the standard succession of the New South Wales Permian. Owing to the writer's impending departure from Australia for some years, time has not been available to study the spore content of every occurrence of Permian coal. Consequently work has been concentrated on the major coalfields, and this paper is to be regarded as preliminary rather than exhaustive in nature.

TECHNIQUE IN THE SEPARATION OF MICROSPORES FROM COAL

The method of isolating microspores from coal has been briefly outlined by Raistrick and Marshall (1939, p. 130). However, the method developed by the writer differs in some respects, and as it will be used in all his later work on Queensland coals, it is described here in some detail.

The coal sample is crushed to pass a 1 mm. sieve, the fraction of this which is retained on a sieve of ½ mm. aperture being sampled for maceration. Coal of this size (½ mm.-1 mm.) is relatively free from dust and fusain, and also contains a smaller percentage of broken spores. A small quantity (about 1 gram) is then mixed with an equal amount of powdered potassium chlorate in a 75 ml. evaporating dish, and concentrated nitric acid added slowly until the dish is half full, ten to twelve times the amount of solids present being added. The liquid is then covered with a watch glass and allowed to stand overnight (16-18 hours). At the end of this time the liquid is diluted and transferred to a 250 ml. evaporating dish and allowed to stand for several hours until the residue settles out. The solution is then removed by siphoning with a bent glass tube, in order to avoid disturbing the light residue at the bottom of the dish. Water is added and the process repeated until the residue is free from acid. At this stage the residue is transferred back to the 75 ml. evaporating dish, and as much water as possible siphoned off. The dish is then filled with 10 per cent. sodium hydroxide solution and allowed to stand overnight. About half the liquid is siphoned off and the remainder diluted to fill a 250 ml. evaporating dish. The washing process is repeated until the solution is clear, allowing it to stand for 3-4 hours between each wash, and finally the residue is transferred to the smaller dish.

The mounting medium used by Raistrick and Marshall (glycerine jelly) did not prove entirely satisfactory for permanent mounts in the summer climate of Brisbane, and was replaced by balsam in xylol. The technique of mounting slides with this medium is as follows:

The microspore residue is mixed thoroughly with about 30 ml. of water, and after allowing about 10 seconds for mineral matter to settle, a small quantity is poured on to a 3 x 1″ glass slide, care being taken not to spread the residue too thickly. The water is then dried off and a few drops of the mounting medium, made by dissolving pre-cooked Canada balsam in xylol, are added. A cover glass is added and the slide heated in the oven for several hours at 40-50° C. The mounts can be examined with reasonable care after an hour, but a longer period is necessary to evaporate the xylol from the middle part of the mount. The number of slides mounted per maceration depends on the abundance of spores in the maceration residue; in the present investigation about 10 to 12 were prepared for each coal sample.

CLASSIFICATION OF MICROSPORE TYPES

The microspores studied have been classified on the basis of physical features according to the method evolved by Dulhunty (1946, p. 147), and adopted as the standard of work on Australian Permian and Mesozoic microspores. The accompanying table (Table 1) indicates the method of classification of the Queensland Permian types. Its main purpose is to demonstrate the classification of new types described from the Queensland coals (marked in the table with an asterisk). In the type numbering, the initial letter P indicates the Permian age of each spore type.

DESCRIPTIONS OF MICROSPORE TYPES

In this section descriptions of new types are marked with an asterisk. Descriptions of types occurring also in the New South Wales Permian are included for the sake of completeness and comparison. They are mainly from Dulhunty (1946), with some changes in dimensions and other features which have resulted from a study of the Queensland examples.

TABLE 1—CLASSIFICATION OF QUEENSLAND PERMIAN MICROSPORE TYPES.

	PSILATE (smooth exine)	GRANULATE (Granular exine)	RETICULATE (Anastomosing ridges or grooves on exine)	ECHINATE (Spined)	STRIATE (Striated exine)	VERRUCATE (warty exine)	MONOWINGED	BIWINGED	TRI-WINGED
Angular tetrahedral; triangular outline TRILETE (Triradiate tetrad scar)	(1) P1A 20-36μ	(6) P6A 30-100μ	(11)	(16) P16A 30-70μ	(21)	(26) P26A 40-73μ	(31)	(36)	(41)
Sub-angular tetrahedral; rounded apices; convex sides TRILETE	(2) P2B* 20–40μ prominent sutures	(7) P7B* 25–40μ	(12)	(17) P17A 40–60μ	(22)	(27)	(32)	(37)	(42)
Ellipsoidal; oval outline MONOLETE (Single tetrad scar)	(3) P3A 40-65μ x 24-36μ P3C 20-30μ x 12-17μ	(8) P8A 40-50μ x 23-28μ	(13)	(18) P18B* 45-55μ x 20-25μ	(23) P23A 50-60μ x 40-50μ transverse striae	(28)	(33) P33A 45-80μ x 25-60μ P33C* 20-50μ x 10-25μ	(38) P38A 40-80μ x 30-60μ	(43)
Spheroidal; rounded outline TRILETE	(4) P4A 20-40μ P4D* 25-35μ thickened portion	(9) P9B 40-100μ	(14)	(19) P19A 28-40μ	(24)	(29) P29A 35-50μ	(34)	(39)	(44)
Spheroidal; rounded outline MONOLETE	(5) P5A 16-40μ rounded opening P5B 45-120μ P5C 14-40μ thick wall	(10) P10B 40-80μ open slit	(15)	(20)	(25) P25A* 14-25μ concentric striae	(30) P30B* 20-30μ small warts	(35) P35A 50-80μ oval wing	(40) P40A 25-40μ small wings P40B 35-50μ large wings P40C 50-80μ small wings P40D 35-55μ lobe wings	(45)

Type P1A (Plate 1, fig. 1A):

Angular tetrahedral; sharply-defined apices; flat or slightly convex sides; triangular outline. Size 20-36 μ from apices of tetrahedron to opposite sides. Trilete; well-developed triradiate sutures extending to distal apices and frequently opened towards proximal apex. Exine psilate.

*Type P2B** (Plate 1, fig. 2B):

Subangular tetrahedral; rounded apices; convex sides, ill-defined triangular outline. Trilete; prominent sutures, straight or only slightly curved, and extending to distal apices. Size 20-40 μ from apices to opposite sides in proximal view. Walls appear relatively thick. Exine psilate.

Type P3A (Plate 1, fig. 3A):

Ellipsoidal. Monolete dehiscence along a line running full length of body gives rise to longitudinal opening expanded towards extremities. Length 40-65 μ; width in lateral view 24-36 μ. Exine psilate.

Type P3C (Plate 1, fig. 3C):

Ellipsoidal. Monolete; longitudinal suture, at times opened with lips turned outwards, runs full length of body. Length 20-30 μ; width 12-17 μ; Exine psilate.

Type P4A (Plate 1, fig. 4A):

Spheroidal; somewhat flattened proximal and distal sides; circular to slightly oval outline. Trilete with frequently opened sutures extending from centre to margin in full proximal view. Diameter 20-40 μ. Exine psilate.

Type P4D (Plate 1, fig. 4D):

Spheroidal; somewhat flattened proximal and distal sides; circular to slightly oval outline. Trilete with sutures extending half-way from centre to margin in full proximal view. Proximal thickened area extending to limits of sutures. Diameter 25-35 μ. Exine psilate.

Type P5A (Plate 1, fig. 5A):

Spheroidal with slight distal and proximal flattening, giving a circular or slightly oval outline. Monolete dehiscence gives rise to large rounded opening on proximal side. Normally small but varies considerably. Diameter 16-40 μ. Exine psilate.

Type P5B (Plate 1, fig. 5B):

Spheroidal to suboblate with circular or slightly oval outline. Monolete with ill-defined suture or elongated area appearing straight or curved, depending on position, but seldom exhibiting distinct opening. Size variable, 45-120 μ. Walls appear relatively thin. Exine psilate.

Type P5C (Plate 1, fig. 5C):

Spheroidal; distinctly flattened and circular outline in axial view. Monolete with short ill-defined suture not seen in many examples. Usually very small with diameter 17-20 μ, but varies from 14-40μ. Exine psilate and very thick-walled giving a dark rim round the body.

The discovery of Queensland spores with monolete sutures confirms the provisional classification of this type; no definite sutures had previously been observed in the New South Wales examples.

Type P6A (Plate 1, fig. 6A):

Angular tetrahedral; well-defined apices; flat or slightly convex sides; triangular outline. Trilete, with long, frequently opened sutures extending to distal apices. Size variable, 30-100 μ from apices of tetrahedron to opposite sides. Exine granulate, normally of fine granular texture, but somewhat variable.

Type P7B (Plate 1, fig. 7B):

Sub-angular tetrahedral, rounded apices; convex sides, ill-defined triangular outline. Trilete with prominent sutures extending to distal apices. Size 25-40 μ from apices of tetrahedron to opposite sides. Exine granulate, of coarse granular texture.

Type P8A (Plate 1, fig. 8A):

Ellipsoidal. Monolete dehiscence, extending full length of body, produces longitudinal marginal opening usually expanded towards its extremities. Length 40-50 μ; width in lateral view 23-28 μ. Exine granulate, of medium-fine granular texture.

Type P9B (Plate 1, fig. 9B):

Spheroidal; slightly to distinctly flattened; circular outline. Trilete with well-developed triradiate slits which frequently tend to trisect the spore. Size variable; diameter 40-100 μ. Exine granulate varying from fine to medium-coarse granular texture.

Type P10B (Plate 1, fig. 10B):

Spheroidal to suboblate; slightly flattened; circular to suboval outline. Monolete; well-developed slit extending the full width of the spore, in lateral view, is usually expanded towards its extremities. Lips of the slit may protrude outwards. Diameter 40-80 μ. Exine granulate, of medium-fine granular texture.

Type P16A (Plate 1, fig. 16A):

Tetrahedral; well-defined apices; flat to slightly convex sides; triangular outline. Trilete with slits extending to distal apices, and frequently opened. Size 30-70 μ from apices to opposite bases of the tetrahedron. Exine echinate with small spines 3-4 μ long, and 1-2 μ wide at base, set 2-3 μ apart.

Type P17A (Plate 1, fig. 17A):

Subangular tetrahedral; rounded apices; convex sides; rounded triangular outline. Trilete with short ill-defined sutures extending towards distal apices. Diameter 40-60 μ. Exine echinate with large widely-spaced spines of regular size pattern. Spines up to 7 μ in length, and 3 μ in width, set about 5 μ apart.

Type P18B (Plate 1, fig. 18B):

Ellipsoidal, with rounded ends. Monolete slit opened for part of its length in some examples, completely closed in others. Length 45-55 μ, width 20-25 μ. Exine echinate, spines up to 5 μ in length and 2 μ in width at base, set about 3 μ apart.

Type P19A (Plate 1, fig. 19A) :

Spheroidal or slightly oblate with circular or slightly oval outline. Trilete with short ill-defined sutures, rarely open. Diameter 28-40 μ. Exine echinate with spines of constant size pattern on each individual, but varying on different individuals from 3 to 6 μ in length, and 1·5 to 2·5 μ in width at base, typically spaced about 6 μ apart.

Type P23A (Plate 1, fig. 23A) :

Ellipsoidal. Monolete suture extending full length of body along lateral margin, normally closed. A narrow frill-like fringe of smooth exine, 10-13 μ wide, is associated with the suture, and projects beyond outline of body in lateral view. Length 50-60 μ ; width 40-50 μ in lateral view. Exine ornamented with transverse striae about 3 μ apart extending full width of body.

*Type P25A** (Plate 1, fig. 25A) :

Spheroidal ; distinctly flattened ; circular outline. Monolete with ill-defined suture not seen in many examples. Diameter 15-25 μ. Exine thin, ornamented with concentric striae about 4-5 in number, from 1 to 2 μ wide and about 3 μ apart.

Type P26A (Plate 1, fig. 26A) :

Angular tetrahedral ; apices well-defined ; sides flat or slightly convex ; triangular outline. Trilete with tri-radiate sutures extending to distal apices. Size 40-73 μ from apices of tetrahedron to opposite sides. Exine verrucate with small, closely-packed, rounded elevations about 2·5 μ in diameter and 1μ apart.

Type P29A (Plate 1, fig. 29A) :

Approximately spheroidal ; slightly flattened ; rounded to slightly oval outline. Diameter 35-50 μ. Trilete with well-marked triradiate sutures extending to margin in full proximal optical section. Exine verrucate with rounded elevations about 2 μ in diameter and 3 μ apart.

*Type P30B** (Plate 1, fig. 30B) :

Spheroidal to suboblate ; slightly flattened ; circular to suboval outline. Appears to be monolete, although definite sutures or openings have not been observed. Diameter 20-30 μ. Exine verrucate with small, closely-packed, rounded elevations about 2 μ in diameter and 1-2 μ apart.

Type P33A (Plate 1, fig. 33A) :

Monowinged with ellipsoidal body. Monolete ; single longitudinal suture about 5 μ wide extending almost full length of body. Body psilate, 45-80 μ long and 25-60 μ wide. Single narrow wing with oval outline, and with faint reticulate marking varying in width from 2 to 7 μ in one individual, situated in lateral plane round body.

*Type P33C** (Plate 1, fig. 33C) :

Monowinged with ellipsoidal body, pointed at each end. Monolete ; ill-defined longitudinal suture usually not extending full length of body. Body psilate, of medium thickness, 20-50 μ long, 10-25 μ wide. Single wing in lateral plane round body, 5-10 μ wide at greatest width of spore, decreasing to 1-2 μ at apices or occasionally not continuous round apex of body. Exine of wing thinner than that of body, psilate.

Type P35A (Plate 1, fig. 35A):

Monowinged with flattened spheroidal body. Monolete character indicated by indistinct, narrow germinal area extending across body. Body psilate, **50-80** μ in diameter. Single wing with oval outline and reticulate venation, continuous in one plane round body, and situated with axis of elliptical outline in direction of germinal area. Width of wing 9-12 μ in direction of germinal area, and **20-30** μ in opposite direction. Narrow zone at junction between body and wing, widest in direction normal to that of germinal area.

Type P38A (Plate 1, fig. 38A):

Biwinged with ellipsoidal body. Monolete, exhibiting narrow, longitudinal germinal area extending full length of body. Body psilate, 40-80 μ long and **30-60** μ wide. Two wings, marked with radiating venation and normally equal to or slightly larger than the body but of variable shape and size, are situated symmetrically on either side of the germinal area towards which zones of attachment extend.

Type P40A (Plate 1, fig. 40A):

Biwinged with slightly flattened spheroidal body. Monolete, exhibiting narrow germinal area extending across body between roots of wings. Body, **25-50** μ in diameter, frequently exhibits coarse striae transverse to germinal area. Two relatively small, somewhat elongated wings marked with radiating venation and normally slightly wider and considerably longer than diameter of body, but of variable shape and size, are situated symmetrically on either side of germinal area towards which zones of attachment extend.

Type P40B (Plate 1, fig. 40B):

Biwinged with slightly flattened spheroidal body. Monolete exhibiting narrow germinal area extending across body between roots of wings. Body psilate, **35-50** μ in diameter. Two relatively large, rounded wings marked with reticulate venation, frequently twice width of body but of variable shape and size, are situated symmetrically on either side of the germinal area with large zones of attachment.

Type P40C (Plate 1, fig. 40C):

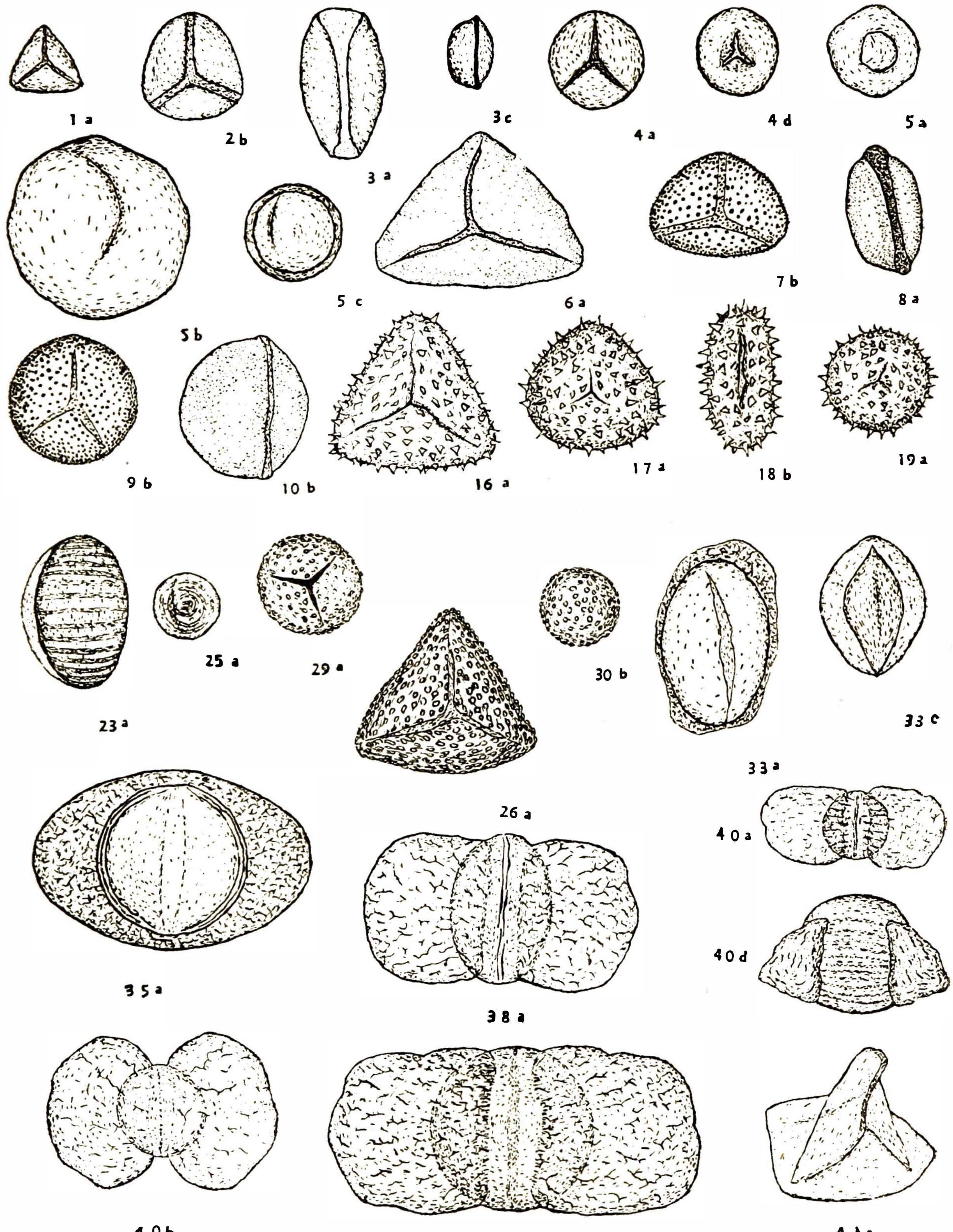
Biwinged with flattened spheroidal body. Monolete character similar to Type P40B. Body psilate, 50-80 μ in diameter. Two wings with reticulate venation, normally rounded or slightly elongated and about same size as body but of variable size and shape, are situated symmetrically on either side of germinal area with large zones of attachment.

Type P40D (Plate 1, fig. 40D):

Biwinged with flattened spheroidal body. Germinal area not evident, but probably situated between roots of wings. Body **35-55** μ in diameter, marked with coarse striae between wings. Two lobe-like wings with wrinkled or folded surfaces, attached symmetrically to one side of the body, protrude only a limited distance beyond its margin, and are directed away from the proximal part of the spore.

Type P41A (Plate 1, fig. 41A):

Although additional examples extending the size range have been found in the Queensland coals, the morphology of this microspore is still not clear. The illustration in Plate 1, fig. 41A, shows the appearance in optical section. The spore



Magnification X 400

appears to consist of a flat disc-shaped portion (25-70 μ in diameter) to one side of which is attached a large elevated structure projecting considerably beyond the margin of the disc. The exine is psilate, and no opening or dehiscence has been observed. As the classification of this microspore is only tentative it has not been included in Table 1.

CORRELATION WITH THE PERMIAN OF NEW SOUTH WALES

The distribution of microspore types in the Permian coals of Queensland is shown in the accompanying table (Table 2). In addition to those included in the table, coal samples from the Baralaba coalfield were studied, but spores were so rare in the maceration residues that only a very few broken individuals were seen, none of which were sufficiently well preserved for identification.

TABLE 2—DISTRIBUTION OF MICROSPORE TYPES IN SOME QUEENSLAND PERMIAN COALS.

Microspore Type	Blair Athol	Bluff	Black-water	Collins-ville	Mount Mulligan
P1A	X	X	X		X
P2B			X		X
P3A	X	X		X	X
P3C	X	X	X		X
P4A	X		X		
P4D	X	X	X	X	
P5A	X				
P5B		X			
P5C	X	X	X	X	X
P6A	X	X		X	X
P7B		X			
P8A	X	X	X	X	X
P9B	X	X			X
P10B	X	X			X
P16A	X	X			X
P17A	X	X			
P18B	X				
P19A	X		X		X
P23A	X				
P25A		X			

Microspore Type	Blair Athol	Bluff	Black-water	Collins-ville	Mount Mulligan
P26A	X		X		
P29A	X	X			
P30B		X			
P33A		X			X
P33C	X	X	X		X
P35A		X			
P38A	X	X		X	X
P40A	X	X			X
P40B					X
P40C		X			X
P40D	X	X			X
P41A	X				X

Of the total of 32 types, 25, or approximately 78 per cent., occur also in the Permian of New South Wales, the remaining 7 types being restricted to Queensland. The high percentage of types common to the two States indicates the wide geographical distribution of individual microspore types in the Australian Permian, and strongly favours their use in correlating the coal measures of one State with those of the other.

With regard to the distribution of microspore types in the New South Wales coals, J. A. Dulhunty has supplied the writer with the following preliminary data :—*

Types P15A and P32A are confined to the Greta Measures.

Types P21A, P33A, and P34A are confined to the Newcastle stage of the Upper Coal Measures.

Type P30A is confined to the Greta Measures and the Tomago Stage of the Upper Coal Measures.

Types P3B, P9A, P13A, P33B, P40A, and P40B are confined to the Tomago and Newcastle Stages (Upper Coal Measures).

Types P28A and P29A occur in the Greta Measures and Newcastle Stage of the Upper Coal Measures, but not in the Tomago Stage.

All other types occur in all three subdivisions of the Permian.

Dealing with each of the Queensland coalfields in turn results in the following correlations :—

Samples from the Bluff coal seams contain type P40A (restricted to the Upper Coal Measures), and in addition types P29A and P33A, which indicate a

* Personal communication dated 18th February, 1946.

correlation with the Newcastle stage. Similarly, the occurrence of types P33A, P40A, and P40B in the Mount Mulligan coals shows that the Mount Mulligan coal measures are approximately equivalent to the Newcastle stage.

The Blair Athol coal contains type P40A, which indicates a correlation of these relatively thin coal measures with some part of the Upper Coal Measures; the presence of type P29A suggests further an approximate correlation with the Newcastle stage. However, owing to the absence of type P33A, and the unusual distribution of type P29A in New South Wales (present in the Greta Measures and the Newcastle stage, but not in the Tomago Stage) the latter correlation is not as well established as in the two previous cases.

Microspores were relatively less abundant in samples of coal from Blackwater, and none of the types recorded are of restricted range. However, from the occurrence of the coal seams in the Upper Bowen series, it is probable that they were deposited at some time within that covered by the Upper Coal Measures.

All the above coal measures are equivalent to, or form part of, the Upper Bowen series. Coal seams of commercial importance also occur in the Middle Bowen series; coal measures of this age are best known in the type area, and there constitute the Collinsville Coal Measures. Reid (1929, p. 97; 1930, pp. 62, 70) has correlated these coals with the Greta series of New South Wales. Samples of coal from the Bowen seam, now worked at Collinsville, were macerated, but unfortunately microspores were very rare in the maceration residues. They were present in the proportion of one or two per slide of maceration residue, and prolonged study revealed only six types, none of which are of restricted range. Consequently the types present do not assist correlation, but the extreme rarity of spores readily distinguishes the coal from the majority of Upper Bowen samples studied, and if it is a constant feature, should be of value in distinguishing between coals from the two series.

CONCLUSION

Now that the microspore types have been described, it should be possible, by study of microspore assemblages, to correlate individual seams, and in this direction lies the future economic application of the present work. Queensland has large areas of unexploited Permian coal measures, including in particular the extension of the Middle Bowen coal measures to the south of Collinsville, and the large extent of the Upper Bowen series in the valley of the Isaacs River. If the richness in coal of the developed areas of Middle and Upper Bowen coal measures can be taken as a guide for such unprospected areas the total reserves of Permian coal in the State may prove comparable with those of New South Wales. The prospecting and development of these North Queensland coal measures is important for the future industrial development of the State, and it is hoped that this investigation will be of assistance in future prospecting and surveying.

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